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Atmospheric Change:

Human Ecology in Disequilibrium

by

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Atmospheric Change: Human Ecology in Disequilibrium

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Abstract

This paper examines global atmospheric change as a problem in human ecology. I argue that persistent anthropogenic changes in atmospheric gases and any consequent negative effects indicate that the present human population, at current levels of economic activity and with existing technology, already exceeds the carrying capacity of the Earth.

I start from the premise that the historic composition of the atmosphere is a product of the co-evolution of the living and non-living components of the ecosphere, and that it has long been maintained in steady-state by self-regulating biological processes. From this perspective, recent rapid changes in atmospheric composition indicate not only that human economic activity is directly altering important ecospheric equilibria, but also that it may be permanently disabling certain negative feed-back mechanisms required to restabilize the system. Such habitat degradation on the level of the ecosphere is a primary indicator that global carrying capacity has been breached.

Because human-induced atmospheric change is a global phenomenon, it has potentially serious consequences for the diversity, distribution, and abundance of much of life on earth, including humans themselves. For example, possible global warming resulting from an increase in greenhouse gases threatens gross world product, *per capita* disposable incomes, the habitability of low-lying coastal regions, world food security, and ultimately world political stability. Developing countries are likely to be hit hardest.

The magnitude of atmospheric and any resultant climatic change is a measure of the maladaptation of modern industrial economies to global ecological realities. However, because of the sociocultural inertia associated with the prevailing material growth paradigm, the scientific uncertainties associated with climatic trends, and the political hazards associated with perceived over-reaction, the policy response to date has been generally restricted to technological fixes and short-term adaptation to the changes themselves. Because it ignores primary causes, mere adaptation to continuing trends places humankind on a dangerously accelerating treadmill. Atmospheric and resultant climatic change can only be reversed by addressing economic growth and the fundamental energy and material basis of society. The implications of this argument for policy are discussed.

Atmospheric Change: Human Ecology in Disequilibrium[1]

Modern society treats atmospheric and potential climatic change as an unfortunate but necessary by-product of material economic progress. By contrast, this paper considers atmospheric change to be a central problem of human ecological dysfunction. My purpose is to make the case that economic activity is already in serious disequilibrium with the ecosphere and to contrast the policy implications of this interpretation with the policy responses currently being generated in the sociopolitical mainstream.

1. CONTRASTING PERSPECTIVES

Mainstream thinking in industrial societies is dominated by the scientific or Cartesian "world-view" which sees the universe as "a vast machine, wound up by God to tick forever... (Berman 1984, p.21; Skolimowski 1981, Jones 1987, 1988). By the end of the 17th Century the scientific revolution led by Decartes, Bacon, and Newton had replaced the ancient organic perception of the Earth as a living entity with a mechanical perception in which humankind was alienated from nature and in which and the latter existed solely for the material benefit of the former. Consequently, industrial society has always regarded "the environment" as a storehouse of resources and a sink for wastes. Otherwise nature is a static backdrop to human affairs.

From this perspective, anthropogenic changes in atmospheric gases are perceived as isolated technical problems or as mere "externalities" resulting from market imperfections. We accept such environmental deterioration as a necessary "trade-off" against economic growth, and believe that it can eventually be arrested through improved technology, better regulation, or other ways of "internalizing" the costs of corrective action. Such approaches result in marginal improvements in the efficiency of human economic activity but do not challenge the nature of humankind's fundamental relationships with the rest of the world.

By contrast, the ecological perspective sees humankind as existing in a state of obligate dependency on the natural world. This more holistic world-view regards quantitative changes in the atmosphere as a symptom of deeper systemic problems in

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[1] Prepared for the Ninth Commonwealth Conference on Human Ecology: HUMAN ECOLOGY, SUSTAINABLE DEVELOPMENT, AND EDUCATION. University of Edinburgh, 19-23 July 1989

the relationship between humankind and the ecosphere. Persistent trends in key atmospheric parameters indicate that the present form of that relationship is unstable and therefore may threaten the long-term integrity of the ecosphere as a whole. This interpretation suggests that we should be acting now to reverse such trends and to re-establish the balance between human activity and ecospheric process. Far from business as usual, it recognizes that such decisive action may involve fundamental changes in the nature of technology and the structure of the global economy.

Since the policy implications of these contrasting perspectives are so clearly different, the question becomes: which perspective most closely conforms to objective reality? Whatever our cultural beliefs, human behaviour must ultimately be constrained by any fixed laws of nature with which it comes in conflict.

2. AUTOPOIESIS: THE SELF-PRODUCING ECOSPHERE

The environment of earth as we have known it is the best possible environment for life as we know it (WER).

Living things evolve in dynamic relationship both with each other and their physical environments. Over geological time, this unconscious mutualism has produced an ecosphere of intricate structure and relationship.[2] The structural components of the ecosphere include everything from simple inorganic chemicals to entire ecosystems. These components do not exist in static isolation but are dynamically related through the continuous recycling of matter and a steady throughput of energy. The entire system is driven by an external source of energy, the sun.

The functional relationships among component parts specifies the unique organization of the ecosphere. By "organization," I mean that peculiar set of relationships that **must be present** for something to exist (Maturana and Varela 1988, p.42). A different set of relationships would define a different system. Thus, the historic organization of the ecosphere is neither inconsequential nor indifferent to change. The removal of key components or the disruption of particular relationships would change the fundamental nature of the system.

It is critical to recognize in this context that the ecosphere shares a singularly important property with other living things: at the whole system level, **the ecosphere is continually self-producing.** The major components of the ecosphere are interdependently linked in a network of transformations and processes whose integrity is essential for the production and maintenance of the components themselves. This type of self-perpetuating relationship is defined as **autopoietic organization** (Maturana and Varela 1988, p.43).

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[2] Some present day ecologists take the contrary position that nature is a disorderly chaos of competitive scrambling and unrelated processes. I believe this reflects a disciplinary insecurity among ecologists in the post-war period culminating in the over-enthusiastic adoption of the reductionist methods of "real" science (physics and chemistry). As a result, we have lost sight of the unified forest among the isolated trees.

A most important implication of autopoiesis should already be clear: much of what we have been pleased to call "the environment" is actually the product of life itself. Living things and their physical environments maintain each other through a variety of positive and negative feedback processes. We have long known that a given species requires a particular set of environmental conditions for survival, but are unaccustomed to thinking that those environmental conditions are themselves dependent on the distribution, abundance, and interaction of species.

Autopoiesis at the global level is related to the current "mild" version of the so-called Gaia hypothesis: over geological time life processes have regulated the physical environment of Earth within limits narrow enough that life has been able to persist.[3] Taken together, autopoiesis and Gaia postulate that the ecosphere as a whole operates as a self-generating, self-stabilizing (or homeostatic) system. This elevates to the planetary level an increasingly important element of ecosystem dynamics: "...characterized by strong positive feedback among its components, [the ecosystem] is in many respects self-generating - its productivity and stability determined largely through its internal interactions" (Perry *et al.* 1989).

2.1 Autopoiesis and the Atmosphere

The atmosphere of Earth is a product of autopoiesis. In the absence of life the atmosphere would be similar in composition to that of Mars or Venus. The proportion of various atmospheric gases would be a chemical equilibrium predictable from the stoichiometry of the gases themselves in reaction with rocks, minerals, and water. Instead, "the Earth has an extraordinary atmosphere, far from chemical equilibrium and apparently kept in that state from one year to the next" (Lovelock 1988, p.53).

While both Mars and Venus have atmospheres composed 95 per cent of carbon dioxide, Earth has only .04 per cent; Mars and Venus have less than 4 per cent nitrogen, Earth 79 per cent; Mars and Venus have just traces of oxygen, Earth 21 per cent. Earth's atmosphere also has methane, while the other planets have none. This last fact means that the Earth's atmosphere contains both oxidizing and reducing agents which are in continuous reaction. Methane (the reducing gas) reacts with oxygen in sunlight to produce carbon dioxide and water. For the present equilibrium to be maintained, 500 million tonnes of methane must be injected into the atmosphere each year along with 2000 million tonnes of oxygen just to replace that lost in oxidizing the methane.

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[3] Lovelock (1979) originally postulated that "the physical and chemical condition of the surface of the Earth... has been, and is, actively made fit and comfortable by the presence of life itself... in contrast to the conventional wisdom which held that life adapted to the planetary conditions ...," but the teleological flavour of this definition and the attendant notion that Earth is a super-organism was generally rejected as fancifully romantic and scientifically untenable. No scientist doubts there are important interactions between living things and the physical environment, but "the holistic nature of the Gaia hypothesis, with the idea that the planet is greater than the sum of its parts... sticks in the throats of mainstream scientists" (Sattaur 1987). Recently, however, the emergent idea of a homeostatic Gaia has begun to attract more adherents from the mainstream for the strength of the testable hypotheses on global feedback mechanisms it has begun to produce (Sattaur 1987, Kerr 1988a).

The important point here is that both gases involved in this equilibrium are the metabolic products of organisms, methane of methanogenic bacteria and oxygen of photosynthesizers, mostly green plants. Similarly, all the other major components of the atmosphere take part in global "biogeochemical cycles" involving continuous material exchanges between living organisms and the physical environment (See Bolin and Cook 1983). Thus to reiterate: "The composition of the global atmosphere is predominantly a product of the biosphere's activity" (Andreae 1989).

Life also has a major role to play in atmospheric thermal regulation. It has been estimated that the atmosphere of a lifeless earth would produce a mean global temperature in the vicinity of 290°C compared to the present mean of 15°C. While the former temperature is much excessive for life as we know it, the latter and the geographic variation around it is just such that some forms of life exist in virtually all the environments of Earth (and some habitats close to the mean display spectacular abundance). This suggests that over geological time, the interaction of living systems with the physical environment has been such as to regulate the exchange of heat between Earth and space.

There is much indirect evidence for this hypothesis. When life began four billion years ago, the sun was probably 20 per cent less luminous than it is today. At the same time, the atmosphere may have contained 1000 times as much carbon dioxide as at present. This, combined with the effects of other greenhouse gases and various factors affecting the Earth's albedo (reflectivity), produced a mean surface temperature estimated at 23°C, quite favourable for the evolution of life as we know it. However, as the sun's luminosity increased by 25 per cent, maintaining temperatures amenable to life would have required the gradual removal of carbon dioxide from the atmosphere.

These conditions apparently favoured the evolution of various marine organisms with calcium carbonate tests and shells. Natural selection needn't have operated solely on the removal of CO_2 *per se* and may have been related to other factors such as enhanced reflectivity in the face of increasing light intensity. In any event, life reduced the thickness of the carbon dioxide blanket "by taking it from the atmosphere and dumping it in the form of limestone in the oceans" (Lovelock 1988, p.54). Massive summer blooms of coccolithophores (species of marine phytoplankton distinguished by a cladding of white calcium carbonate plates [coccoliths]) are currently being investigated for just such a potential role in global climate regulation (See Mlot 1989a).

2.2 Autopoiesis as Context for Sustainable Development

The foregoing indicates that the character of the pre-industrial atmosphere was very much the product of living systems evolving over billions of years. Throughout this process, life constantly adapted to changing external factors (e.g., increasing solar intensity) as well as new conditions created by life itself (e.g., the oxygenation of the atmosphere) while maintaining key environmental parameters within a viable range. The more or less stable conditions of recent millennia are maintained by numerous known physical and biological feedback relationships and undoubtedly many more are as yet undiscovered.

Understanding autopoiesis and similar "Gaian" concepts is critical to developing rational, sustainable, environment and development policy. Truly sustainable development must be geared to the maintenance of the ecospheric mechanisms upon

which our socioeconomic systems are dependent. Rather than a static backdrop, "the environment" has become very much the play itself.

3. HUMAN IMPACTS ON THE ATMOSPHERE

> Humanity is conducting an unintended, uncontrolled, globally pervasive experiment whose ultimate consequences could be second only to nuclear war (Canada 1988).

As we approach the 21st Century many authorities assert that **atmospheric and climatic change looms as our most serious global environmental issue** (Canada 1988, Smith and Tirpak 1988, Warrick and Jones 1988). This section therefore documents some of the data and speculation supporting this assertion. Limited space confines the discussion to greenhouse gasses and aspects of the ozone problem, but it is worth noting that these examples illustrate many of the characteristics of other worrisome global environmental trends.

Before considering the data, we must underscore the importance of distinguishing between the known and the uncertain, the measured and the predicted, in the interpretation of climate change scenarios. For example, while the greenhouse effect *per se* and human-induced increases in greenhouse gases are not in dispute,[4] there is disagreement over the likely climatic effects of these increases. This is partially because standard climate models do not yet account for numerous positive and negative feedback mechanisms that may significantly influence events (and may never achieve an adequate level of sophistication). Incomplete knowledge and simple models inevitably introduce great uncertainty into the prediction of climatic trends. (See Shabecoff 1989, Solow 1989.)

3.1 Greenhouse Gases and Climatic Change

Cause...

Greenhouse gases are so called because they have the capacity to alter the thermal equilibrium between the earth and space. The accumulation of these gases in the atmosphere results in greater heat retention and the gradual warming of the air, land, and waters of the planet to a new equilibrium.

- Carbon dioxide (CO_2)is a major potential contributor to potential changes in climate, particularly global warming. It accounts for about half of the projected greenhouse effect. Atmospheric concentrations of CO_2 have increased from pre-industrial levels of 280 parts per million by volume (ppmv) to 346 ppmv in 1985. This is a human-induced increase of 25 per cent.

- Today's levels of atmospheric CO_2 are higher than at any time within the past 160,000 years and are still increasing rapidly (Barnola et al. 1987).

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[4] Historic levels of greenhouse gases produce a mean global temperature of 15°C. Without this protection, the mean temperature would be -18°C.

• While deforestation has been a major contributor (up to 50%) in the past, 80% of today's CO_2 emissions are from fossil fuels and these will continue to be the major source in the future (Bolin 1986).

• Most analysts agree "carbon dioxide concentrations will continue to increase for at least the next 50 years" even assuming strong emphasis on alternative energy and conservation (Warrick and Jones 1988, p.50).

• The majority of the world's population who live in developing countries account for only 13% of CO_2 emissions compared to 57% by industrialized countries. Thus, any world strategy to reduce emissions must confront distributional inequity in energy use and pressure to expand consumption in the Third World for economic development (Warrick and Jones 1988).

• Other greenhouse gases are also increasing rapidly. Methane concentrations have doubled in the last 200 years and are increasing by 1% per year (Rasmussen and Khalil 1986). Methane contributes 18% to human-induced greenhouse warming at 1980s levels (Rind 1989).

• Chlorofluorocarbons (CFCs), best known as the cause of ozone depletion, are also important greenhouse gases. They are long-lived, have 10,000 times the radiative effect of CO_2, and are increasing at 5-7% per year (Bolle et al. 1986). CFCs may now be second only to CO_2 in their contribution to global warming.

Effect...

A recent scientific "Forum on Global Change and Our Common Future" in Washington DC agreed that a major stratospheric cooling is virtually certain and that there is a 90 per cent chance that "Earth is slated for a 2-6 C° increase in global average temperature from a doubling of carbon dioxide in the next 50 to 100 years..." (Mlot 1989b, p.428). Indeed, according to recent computer analyses, enhanced greenhouse warming is no longer a threat but a reality. James Hansen, head of the Goddard Institute of Space Studies, has state "with about 99% confidence" that the temperature rise of the past 30 years is a real trend, not just a random occurrence (Hansen 1988).

• There has been an increase of average global temperature of 0.5-0.7 C° in the last 100 years (Canada 1988).

• Present global temperatures are the highest in the history of instrumental records. 1988 was the warmest year on record, and the six warmest years in the last 100 have occurred since 1980 (British Meteorological Office and University of East Anglia 1989).

• The estimated production of greenhouse gases will likely result in a committed (i.e., unavoidable) rise in global mean equilibrium air temperature of 0.8 C° to 5.4 C° by 2030. (The actual or transient warming in 2030 is likely to be 0.6 C° to 3.1 C°.) (Warrick and Jones 1988).

• Warming even in the middle of this range would result in a warmer global climate "than at any time within the last 120,000 years" (Warrick and Jones 1988, p.54).

• "Warming to the level attained at the peak of the current interglacial and the previous interglacial [0.5 to 1.0 C° the 1951-1980 levels] present appears to be inevitable" even with drastic and probably unrealistic reductions in greenhouse gas forcing (Hansen *et al.* 1988).

• Due to thermal inertia of the oceans (it takes time for the seas to warm up) global mean temperature approaches the equilibrium level for a given concentration of greenhouse gases only very slowly. For 1980, this lag effect was estimated at 20-60 years. (This explains the difference between transient and equilibrium temperatures noted above.)

• Because of this delay, global warming would continue for decades even if we halted the accumulation of greenhouse gases today (Hansen et al. 1984).

• Marked variations in warming can be expected. Warming may be greater in winter than summer and high latitudes may experience twice the global average temperature increase (various sources). However, the various climate models differ in their projections of the geographic distribution of temperature change (See Hansen *et al.* 1988).

...and Potential Consequences for Food Security

Existing data and computer simulation models indicate that:

• Global warming will be accompanied by changes in the amount and distribution of rainfall, the frequency and distribution of heatwaves, and the length of growing season (Smith and Tirpak 1988). The effect on agriculture will be mixed, depending on crop types and the geographic distribution of climate change. While estimating the net impact is difficult...

• Higher temperatures and reduced precipitation will likely result in lower soil moisture in two of the world's major food-producing regions, the North American heartland and the grain-growing areas of the Soviet Union.

• "Much of the land in the US Great Plains that produces wheat would revert to grassland. The western US cornbelt would become semiarid...." "On the plus side ...the winter wheat belt would shift northward, with winter wheat yielding 2.7 tons/ha. replacing spring wheat yielding just under 2.0 tons/ha. (Brown 1988, p39).

These latter predictions are particularly significant considering the North American drought of 1987 and 1988. While we cannot state with certainty that this drought was caused by greenhouse enhancement, the general warming trend with which it was associated is consistent with greenhouse expectations (Wigley et al. 1985) and with various models predicting increasing frequency and severity of drought (e.g., Williams *et al.* 1988). In this light consider the following:

• Since 1950, three US corn harvests have been severely reduced by drought. Each reduced harvest occurred during one of the six years since 1980 described as the warmest in the last century.

• From the beginning of the 1987 harvest to the beginning of the 1989 harvest, **"world reserves of grain [more than half of all human caloric intake] will have dropped from the highest level ever to the lowest since [just after] WW II"** (Brown 1988). Estimated carryover stocks will be only 54 days of consumption.

• The 1988 drought was by many criteria the most severe ever to afflict the US: "...For the first time in decades... the US ran up a 10-million-ton food deficit and had to dig into its food reserves" (Bertin 1989).

• Another severe drought in the US and Canada in 1989 "would reduce exports to a trickle, **creating a world food emergency**" (Brown 1988, USDA 1988).[5] (North America normally produces most of the world's grain surplus.)

To put this in a global context note that:

• After unprecedented growth between 1950 and 1980, world grain production leveled off in 1985 and 1986 and fell sharply in 1987 and 1988. In *per capita* terms, it fell in each of these last four years (14% in total).

• While technology has yet to be fully exploited in some areas, "the backlog of unused agricultural technologies that farmers can draw upon in some countries is dwindling" (Brown 1988, p.7).

• Agriculture everywhere is increasingly constrained by ecological trends including loss of topsoil, excessive runoff, waterlogging and salting of soil by irrigation, falling water tables, farmland conversion, and now possibly climate change (Pimentel *et al.* 1987, Brown 1988, Brown *et al.*1989).

• If these data were adequate to aggregate for the world as a whole, "it undoubtedly would show that **sustainable world food output is now running well below consumption**" (Brown 1988, p.7).

• In the mid-80s, grain production plateaued in some of the world's most populous countries, including India, China, Mexico, and Indonesia.

• Meanwhile, world population continued to grow by 88 million per year in 1988 and is projected to reach 91 million in the early nineties.

3.2 The Ozone Problem

Stratospheric ozone shields living organisms from the potentially harmful effects of ultraviolet radiation (UV) from the sun. In the 1970s scientists predicted that if chlorofluorocarbons (CFCs or freons)[6] reached the stratosphere, their normally stable chlorine-fluorine bonds could be broken by UV, setting free atoms of chlorine which in turn would destroy the ozone. In 1985 the British Antarctic Survey reported a springtime loss of 40 per cent of the ozone over the Antarctic. Accumulating evidence that this was a real phenomenon led to the Montreal Protocol

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[5] There is, however, a great deal of flexibility in the system. More than a billion people could be fed with the grain and soybeans currently consumed by livestock in the US alone.

[6] Highly stable (at sea level) non-toxic chemicals widely used as refrigerants, propellants, and blowing agents.

of September 1987 to regulate world production and use of CFCs. As shown below, more recent findings have suggested this historic agreement may already be obsolete.

• Initial observations of ozone thinning by the US in the 1970s were overlooked by computers programmed to ignore large declines as erroneous and by scientists who had fallen behind in their data analysis. Similarly, British and Japanese scientists held back their early data on sudden losses over the Antarctic, attributing them to instrument error.

• At that time, scientists believed only 1 out of every 100 liberated chlorine atoms would destroy ozone. According to theory, the rest would be bound by nitrogen. However, the problem was still serious since each free chlorine is able to eliminate about 100,000 ozone molecules.

• By 1985, the evidence of an Antarctic ozone hole led the US to dispatch two technically sophisticated expeditions to examine the problem. Their results, released in 1988, found massive destruction of ozone throughout a seasonal "hole" in the ozone layer up to twice the size of the United States. In some places destruction was essentially 100%. The damage was beyond reasonable doubt caused by CFCs.

• The ozone depletion was so much greater than predicted because instead of only 1%, **all liberated chlorine atoms are free to destroy ozone.** This "new" chemistry probably operates throughout the stratosphere, though at lower rates than at the poles.

• Ozone losses are now being documented away from the poles. Between 30° and 60° North (where most people live) column ozone declined 1.7%-3.0% between 1969 and 1986.

• These findings are all the more alarming because: a) the Montreal Protocol is based on the "old" chemistry (the negotiations were going on while the ozone hole was being investigated) and b) **present observations of ozone thinning result from releases of CFCs in the 1960s and 1970s.** We have yet to see the results of 1980's releases. (It takes a lag of several years for CFCs to reach the stratosphere.)

• Nearly 362,000 metric tons of CFCs continue to be released annually. The Montreal Protocol was to reduce CFC production by 50% by 1999, but the US Office of Technology Analysis has argued that even if stringently implemented actual reduction would be only 15% to 35%. (More recent discussions aim at revising the protocol to achieve 100% elimination by century's end.)

• Some of the so-called "safe" CFC substitutes suggested so far will still destroy ozone at a reduced rate and will also contribute to greenhouse enhancement.

• Halons, a separate class of bromine-based compounds have been found to be three to 10 times more destructive of ozone than CFCs and may already account for 10% of ozone thinning. Halon concentrations in parts of the stratosphere are increasing by 15%-25% per year.

Direct Impacts of Ozone Depletion

• Each 1% decline in ozone is expected to result in a 4% to 6% increase in certain skin cancers and a significant rise in eye damage.

• Preliminary experiments on Antarctic marine photosynthesis have found that shielding phytoplankton from ambient UV increases production by two to four times; conversely, photosynthetic rates are greatly reduced under enhanced UV. A 35% drop in production has been predicted from a 25% reduction of ozone.

• Of 200 species of terrestrial plants tested, 70% have been found sensitive to UV-B radiation. Productivity losses of 1%-2% for each 1% reduction in ozone seem possible.

• These data support concerns that increased UV may have profound negative effects on primary production, wildlife, and ecosystem structure and function generally. Significant losses of phytoplankton and a decrease in net primary production would also increase atmospheric CO_2 thereby "feeding back" positively on greenhouse enhancement.

• The exact nature of global ozone trends will not be clear before new satellite monitoring capacity is put in place in 1991, and perhaps not before the end of the century. It does seem clear that ozone destruction will continue and even accelerate for decades. **Even total elimination of the production of CFCs, halons, and other ozone depleting chemicals would not allow the ozone layer to recover in less than a century.**

(Ozone data compiled from: Anderson 1989; Brown *et al.* 1989; Canada 1988; El-Sayed 1988; Kerr 1988b; MacKenzie 1988; and Stafford 1988.)

4. ANALYSIS: HUMAN ECOLOGICAL DYSFUNCTION

It is clear that human activity is now both directly changing key atmospheric parameters while simultaneously altering the structure of the ecosphere (e.g., through deforestation). These structural changes may, in turn, induce further deviations in the atmospheric parameters. The combined effect of these interventions and the feedback among them is unpredictable but potentially disastrous to major ecosystems and ultimately to human beings themselves.

4.1 Climatic Change and the Ecosphere

Most studies agree that the expected climate change could move climate belts in continental mid-latitudes north by 500-700 kilometres (south in the southern hemisphere).[7] This would dramatically affect the geographic ranges and available habitat of thousands of plant and animal species (Cohn 1989, Pain 1988, Smith and Tirpak 1988). It is this sort of geographic shift in climate pattern that threatens the present relative stability of agriculture as noted above. The anticipated rate of change may be 10-40 times as fast as that after the last ice age and threatens many life-forms with extinction.

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[7] In mountainous areas, this would be the equivalent of a 1000 metre upslope shift.

Impacts on Plant Communities...

Because individuals are immobile, plants will be most severely affected. For example, while shifts of 500 km in suitable range could occur within 40-80 years, forests can only migrate 20-60 km per century. Thus, great changes in forest distribution, composition, and quality can be anticipated. Dieback may be severe in the southern parts of present ranges in response to rising temperatures and declining soil moisture. Moreover, trees weakened by climatic stress will also be less resistant to attack by insects, fungal parasites, and other diseases.

Such effects may be visible within 30 years. In pure economic terms, they obviously create great uncertainty for the forest sector respecting both security of supply and appropriate silvicultural strategies (trees planted today may not be able to mature if suitable climate has migrated north).

There are two additional complications in much of the developed world. First, the stress of climate change will be added to the stress already being imposed on forests by acid precipitation and air pollution generally. In the last decade, forest decline has become endemic in central and eastern Europe and is now also affecting the forests of much of eastern North America (Hinrichsen 1987). It is likely that climate change will act synergistically with the present causes of forest dieback to accelerate the damage. Second, the death and decomposition of trees and the loss of forest productivity generally will add to atmospheric carbon dioxide, exacerbating the spiral of decline.

Animal Life...

Although animals are more mobile than plants they too will be forced to adapt. However, it is not just a simple question of moving. The shift in climate belts will create new communities of plants and animals that may or not be suitable for particular species. Changes in climate will affect established equilibria in the interactions among species such as competitive, parasite-host, and predator-prey relationships, tilting the balance a different direction. Differential rates of adaptation may also be problematic. While bacteria and fungi evolve quickly in response to environmental change, plants and animals do so more slowly. This means there may initially be serious imbalances among key species groups in the new ecosystems. All such factors affect the probability of a given species being able to adapt to new conditions.

Shifting their home range may simply not be possible for many animals currently restricted to "islands" of suitable habitat surrounded by areas modified by human activity. Without suitable corridors connecting such populations to areas of future habitat, they will simply be "drowned" by climate change (This is also a problem in mountainous areas where there may be no upslope into which populations can migrate as the world warms.) Many populations and species may be lost.

Regular migratory species will be among the first to disappear. For example, the annual migrations of many bird species are timed so that migrants arrive at appropriate stop-over sites or their breeding habitats at the peak of available food supplies. However, the birds' patterns are stimulated by increasing daylength which remains unaffected, while food supplies may be cued by temperature which will be enhanced. Hence species migrating North may arrive too late to take full advantage of the annual explosion of insects upon which they are dependent to feed their

young. Disruption of long-entrenched patterns of synchrony may be one of the more important impacts of climate change (Pain 1988).

...and Human Beings

People will be confronted with many of the same problems as other plants and animals as our habitats everywhere are affected to a greater or lesser extent by global climate change. While we cannot predict the exact impacts with precision, the anticipated magnitude and rate of change is greater than any experienced in human history.

Not all the impacts will be negative. For example, some studies project that northern agriculture will benefit from higher mean temperatures and longer growing seasons, and that in the longer run, deserts will bloom from increased rainfall (See Miller and Pearce 1989). However, the larger question remains whether increased productivity in benefitting regions will compensate for losses expected elsewhere from more frequent or severe drought. Soil limitations may also be a factor - agriculturally suitable soils do not migrate north with the climate that produced them.

On balance, the likelihood is that atmospheric and climatic change will reduce the productivity of many important resource systems; impose substantial social and economic costs on adapting populations; and exacerbate the negative ecological impacts of existing and future development (the synergism effect). While humans have the advantage of being able to adapt socioculturally and technologically as well as behaviourally, many countries will be stretched to their economic and political limits if the mid-range climatic scenarios come to pass. This scale of change could result in whole regional populations being displaced by enhanced desertification, coastal flooding, or other forms of landscape degradation. (See Jacobson 1988.)

Such considerations as this have led some analysts to suggest:

...that the climatic changes and the first order effects identified in the literature, will have significant downward impacts on world production and gross national products and on the *per capita* disposable income of the world's residents (Ireland 1988, p.13).

Major sources of economic loss include: diversion of capital to non-productive infrastructure to protect society from rising sea levels; higher maintenance and replacement costs for coastal structures; direct losses of land, and falling property values with loss of coastal amenities; lower agricultural, forestry, and fisheries production in many areas; higher material and production costs in related industries and therefore lower incomes; facilities and plant relocation away from hazards or in response to shifting production; labour force relocation and training; aid to stressed nations; funds to assist environmental refugees, etc. Whether such costs are one-time, permanent, or ultimately recoverable, "world GNP [by 2030] will be lower than would otherwise be the case if no climatic changes were to occur" (Ireland 1988, p.14-15).

The ability to respond to the effects of climatic change will depend not only on the regionally specific magnitude and rate of change, but also on a variety of sociocultural, political, and economic factors. For example, industrial countries are not as dependent on the primary resource sectors as are many developing countries, and some in mid- and high latitudes may enjoy both positive and negative economic

consequences of climate change. The industrialized nations also have greater financial and technological resources to cope with any socioeconomic dislocation associated with climate change than do developing countries. Thus, conventional wisdom suggests that industrialized countries will be able to adapt more effectively than less developed countries to the socioeconomic consequences of climatic change.

It is conceivable, however, that some advanced, highly urbanized nations have become excessively dependent on patterns of development, trade, and supply that cannot be maintained in the warmer world of the future. These countries may actually find adjustment more difficult than do certain less developed (but more flexible) nations whose people live closer to the land and are accustomed to hardship.

Whatever the regional variation, there is clearly a significant geopolitical dimension to the problem of climatic change. Arguably, "without well-designed and implemented limitation and adaptation strategies, [climatic change] will add to the world's inequalities, instability, and insecurity" (Ireland 1988 p.25).

4.2 The Human Ecology of Climatic Change

For two centuries, an industrializing world has acted as if the environment were a given, permanently fixed by simple mechanical laws. Indeed, the very term "environment" sets nature off as separate from and somehow less important than ourselves. By this perception, human activity is unlikely to have any significant or lasting impact on the external world. In any case, should something go wrong, simply backing off will set things right again.

An ecological interpretation paints a different picture. First, as we have already seen, "the environment" is a dynamic feedback system subject not to mechanical but to thermodynamic laws. Second, humankind does not exist apart, but is a single, if increasingly dominant, component of the ecosphere (e.g., Vitousek *et al.* 1986). Third, we are clearly now capable of catastrophic impacts on the ecosphere and many of the changes may be permanent.

For all its seeming organizational and technological sophistication, the human economy is "fundamentally directed toward a problem encountered by all other species - the dependence for life on materials from elsewhere in the [ecosphere]" (Rapport 1984). From this perspective, it is the current rate of extraction of materials from the ecosphere and the disposal of all such materials back into the ecosphere, that lies at the root of our environmental problems. Unlike other species whose populations are limited by negative feedback mechanisms, the human population exploded with the industrial age and continues to grow at 88 million per year. Meanwhile, economic expectations everywhere are on the rise resulting in increasing rates of per capita consumption. In short, the human system is dominated by positive feedback which places exponentially increasing demands upon the ecosphere.

Breaching Carrying Capacity

Unfortunately, both the productivity of the ecosphere and its capacity to recycle "wastes" produced by the human economy are limited and the evidence indicates that demands imposed by present human populations using current technologies already exceed both limits. This raises the question of planetary carrying capacity and its implications for policy.

"Carrying capacity" is defined as the population of any species that can be supported indefinitely in a defined area without causing permanent damage to its habitat. For any human population this can be translated into the kind and level of economic activity that can be sustained over the long term without damaging the ecosystems upon which the population is dependent (Rees 1988, 1989). Since people are active components of all major ecosystems, it is realistic to be concerned about global carrying capacity and the status of the ecosphere as a whole.

This perspective sees any persistent deterioration in key ecological parameters as an indication of imbalance between the demands of the human population and the carrying capacity of our global habitat. Steadily increasing greenhouse gases, global warming, rising CFC levels in the stratosphere, and the deterioration of the ozone layer are all indicators of human ecology in disequilibrium.

As noted, negative feedback mechanisms, particularly enhanced photosynthesis and the "dumping" of carbon into relatively permanent marine deposits, are capable of controlling limited increases in atmospheric carbon dioxide. However, total anthropogenic carbon dioxide production is currently about six billion metric tons annually, of which only three billion are being absorbed by these homeostatic mechanisms. The three billion metric tons accumulating annually in the atmosphere is therefore a direct measure of the extent to which deforestation and our fossil fuel-based economy exceeds the limits of the carbon dioxide equilibrium. Similarly, ozone is constantly being created and destroyed by chemical processes which have long been in equilibrium in the stratosphere. The rate of ozone depletion is therefore a measure of the extent to which CFCs, halons, and related synthetic chemicals have destabilized that system. These and numerous other induced ecological trends testify that humans have collectively breached the carrying capacity of the Earth.

Given the complexity of ecospheric relationships, it is hardly surprizing that persistent trends in the atmosphere accentuate each other (positive feedback). For example, ozone destruction in the upper stratosphere allows ultraviolet radiation to penetrate deeper into the atmosphere before giving up its energy. This in itself will add to any greenhouse warming (Gribbin 1988). In addition, the increase in ultraviolet radiation may suppress photosynthesis. The resultant decline in marine productivity and forest growth would reduce carbon dioxide uptake and further exacerbate the greenhouse effect.

There is a positive note: by trapping heat in the lower atmosphere, greenhouse gases contribute to cooling the stratosphere which some believe may slow down the rate of ozone depletion. However, any benefits of this may be more than cancelled out if the colder stratosphere provides "a less effective lid on convection from the troposphere below, altering wind and weather patterns worldwide" (Gribbin 1988).

The Bottom Line: Human Ecological Dysfunction

If, with existing technology, the human economy already exceeds global carrying capacity, it is particular cause for concern in an era of growing population and rising material expectations. Because of positive feedback, the continued expansion of the global economy may force the ecosphere into a sequence of unpredictable, destructive, feedback cycles. There is simply no guarantee that future environmental changes will be gradual or reversible as implicitly assumed by society. In fact, no thermodynamic processes are precisely reversible. Numerous examples exist of qualitative "surprise" in the behaviour of stressed ecosystems, behaviour that deviates profoundly from management's equilibrium expectations (Holling 1986).

The longer present trends continue, the more likely we are to reach critical thresholds of unpredictable systems behaviour that will not necessarily be amenable to human society. The probability of such chaotic behaviour increases the more human beings simplify the ecosphere. "At certain points in the unfolding process, individual actions have great significance. This is especially pertinent to the macro-level of human societies and our interactions with natural ecosystems" (Prigogine and Stenges 1984, p.300). The extinction of species, the destruction of ecosystems, the spread of monoculture - all such trends tend to undermine the present homeostasis of the entire system by reducing the variety of response mechanisms.

The mechanical world-view is obsolete. However powerful our technologies, whatever else we might prefer to believe, the reality is that atmospheric destabilization is indicative of serious human ecological dysfunction. People live in a state of obligate dependency on the integrity of the ecosphere, yet we are in danger of permanently disrupting the processes and relationships which sustain us and which have long determined our own species' distribution and abundance.

5. CONCLUSIONS: POLICY IMPLICATIONS OF ATMOSPHERIC CHANGE

5.1 The Decision-Makers' Dilemma

Atmospheric and associated climatic change shares several characteristics with other environmental metaproblems which make them particularly intractable to policy and management:

- While the political decision-making process prefers certainty and predictability, **both the magnitude and precise effects of atmospheric change and other global ecological problems are clouded with uncertainty.**

- In some cases, the uncertainty is absolute. Where critical physical or ecological mechanisms are as yet unknown to science, **ecological impacts cannot be predicted or discovered until they occur.** (For example, we have come to understand many dimensions of the ozone and acid rain problems only after the fact.)

- The inherently "systems" nature of environmental problems confounds our compartmentalized and fragmented management institutions. For example, **future energy policy is likely to have a greater impact on food security than is agricultural or development policy.**

- Internal homeostatic mechanisms confer great resilience and inertia on global ecosystems which results in lags of years or decades between cause and effect. This applies equally to damage-causing activities and corrective responses. **The initial lack of signals from the environment that something is awry leads us into an ecological trap.** On the one hand, it produces sociopolitical inertia when action is required, and on the other it delays the benefits when decisive action is taken.

- The lag effect also means that: a) major ecological problems can only get worse even after appropriate action has been taken; and b) if we wait for certainty before taking action, it may be too late. **Political hesitation may result in irreversible damage to critical atmospheric and related ecosphere processes.** (As noted, nothing we can do today will repair the ozone layer in the foreseeable future.)

• Decision-makers will increasingly be confronted with choices between alternative "what if" scenarios. To this extent, **environment-related decisions will be based more on political judgement calls than objective technical analyses.** This reality underscores the importance of public education on global environmental change, so that painful but necessary policy initiatives will be politically acceptable.

5.2 Policy Responses

> Ultimately we cannot stop acid rain or other forms of air pollution without changing our daily lifestyle, our consumption patterns and investment decisions (Carroll 1989).

Partially because of the numbing uncertainty noted above, but as much attributable to sheer inertia, there is little concrete evidence yet that society is willing fundamentally to change its ways in response to atmospheric change. There is heightened awareness of the problem, and general agreement that something must be done, but so far the political process has stopped short of action that would call for significant changes in lifestyles or future economic expectations.

The level of political rhetoric on the changing atmosphere has increased greatly in recent years in response to the perceived "greening" of the public and several international accords on environmental issues have recently been signed or are in negotiation. However, even such remarkable agreements-in-principle as that reached by 81 nations in Helsinki in May, to ban CFCs by the end of the century (by revising the Montreal protocol), "will come into effect only if acceptable replacements for the outlawed chemicals are available" (MacKenzie 1989).

5.3 A Canadian Example

The June 1988 world conference on "The Changing Atmosphere" in Toronto recognized the role of accumulating of carbon dioxide (CO_2) in the atmosphere in greenhouse warming and recommended:

> Targets for energy supply should be directly related to reductions in CO_2 and other greenhouse gases. A challenging target would be to reduce the annual global CO_2 emissions by the year 2005 through improved energy efficiency, altered energy supply, and energy conversion (Canada 1988, p.8).

In his statement to the conference, Canada's Prime Minister Mulroney seemed to agree with this assessment: "In no area is the link between our economic activity and environmental disruption more evident or more troubling than in the area of energy policy. Canada is committed to applying the principles of sustainable development to our energy future." Yet less than a month later, his government had announced a $1 billion grant and $1.7 billion in loan guarantees to a consortium of oil companies to develop the Hibernia east coast off-shore oil field. These gifts from the Canadian taxpayer will enable Hibernia to produce the world's most expensive oil at market prices by the mid-1990s. Nor was this largess to the hydrocarbon sector to stop here. Within weeks, the subsidy had grown to $5 billion as a series of western energy megaprojects were added to the pork-barrel list.

Significantly, Article 906 of the Canada/US free trade agreement (negotiated by the Mulroney and Reagan governments and implemented on 1 January 1989) allows for "existing or future incentives for oil and gas exploration, development, and

related activities in order to maintain the reserve base for these energy resources (emphasis added)" (Canada 1987).

Meanwhile, federal government support for renewable energy development will be cut almost in half between 1988 and 1993 to a five year total of $253 million, or 5% of the recent commitment to hydrocarbon subsidies (CREIC 1988).

What the world needs to reduce atmospheric carbon dioxide are realistic (higher) energy prices for conventional energy, sound conservation policies, and research and development of alternative energy. What our leaders are providing in North America are subsidies to oil and gas that help keep prices artificially low, discourage conservation, and inhibit the search for ecologically benign alternatives. In the final analysis, policy is what gets done, not what gets said.

5.4 A Range of Policy Alternatives

There are basically four levels of policy response to global climate change.:

1. Do nothing: This involves hoping for the best and letting society adjust unaided to whatever occurs. This option implicitly assumes low risk and predictable, manageable, systems behaviour. Essentially it's business as usual.

2. Treat the symptoms: This is low level adaptation that includes various forms of mitigative action to reduce the effects of change (e.g., crop and flood insurance, and emergency relief). The assumption here is that likely levels of environmental change will not seriously challenge the *status quo*.

3. Reduce exposure: This is a more profound form of adaptation involving such things as building dykes, resettling populations, switching crops, and changing to more sustainable land uses.

4. Attack the cause: This level of response is the only one that attempts to reverse the direction of negative trends. This option assumes we are in crisis now, immediate evidence to the contrary. The risk of delay is perceived to be great and while the detailed behaviour of the system is unknown it is presumed likely to be detrimental if not disastrous to society.

The uncertainty inherent in present scientific data is such that a case could be made in support of any of these response categories. Variations on Levels 1 and 2 are preferred by many technological optimists and mainstream macroeconomic planners. Indeed, almost all policy and planning relevant to global change to date has been addressed to biding our time or treating initial symptoms. More recently, mounting fear of such things as frequent drought and rising sea levels has begun to have an effect. For example, farmers in the prairies of North America are looking for more drought-resistant crops and there are numerous studies of the dyking and dredging requirements of sensitive coastal areas (Level 3). Level 4 is the choice of many environmentalists, so-called deep ecologists, and strong proponents of the Gaia hypothesis. Tentative moves in this direction are now being made through, for example, efforts to upgrade the Montreal Ozone Protocol.

Assuming that at least some ecological problems are serious, and given the "commitment" we have already made to such trends as global warming and ozone depletion, some socioeconomic adaptation to environmental change is necessary and unavoidable. However, adaptation by itself is an ecological treadmill involving

incalculable economic costs down the road.[8] If current trends are evidence of systemic disorder, and we are not prepared to address the causes, the global ecocrisis can only get worse.

Only by going to the root of the problem (Level 4) can we reduce the impacts of human activity on the ecosphere, and hope to reverse ominous trends. This would involve such measures as:

- banning ozone depleting gases;
- rapidly phasing out of fossil fuels;
- reorienting forestry to the growth of carbon sink forests (perhaps funded initially by an "entropy tax" on fossil fuels which would have the additional advantage of reducing consumption and encouraging the development of viable alternatives [Rees 1989b]);
- eliminating toxic pollution;
- developing more efficient and ecologically benign technologies;
- reducing material consumption and expectations (at least in the industrial world);
- creating new social safety nets to catch workers displaced from ecologically inappropriate employment;
- creating new forms of paid employment in programs designed for ecosystem rehabilitation;
- diverting resources from arms production and the military to soils, fisheries, water, and forest rehabilitation, and;
- forgiving Third World debt (and otherwise confronting the equity issue);
- otherwise committing to ecologically sustainable forms of development (Rees 1988,1989a).

This route is the only way to avoid predicted calamities and also reduce the likelihood of triggering previously unknown phenomena.

It is worth noting that Level 4 responses are implicitly interventionist, and involve a high degree of cooperation and collaboration between the public and private sectors. They also involve wealth redistribution measures both within nations and between the developed and developing world. As such, they fly in face

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[8] For example, as much as US $111 billion (1988 dollars)just to protect present coastal installations in the US by the year 2100, and 7000 square miles of dryland could still be lost (Smith and Tirpak 1988 p.15).

the of the new conservatism, particularly the trend to deregulation and emphasis on the marketplace as the wellspring of social value.

Ironically, the growth and development patterns encouraged by present policies creates higher socioeconomic dependency on ecosystems stability while simultaneously inducing greater fragility. Thus, while many jurisdictions are weakening their management and enforcement capability, what they need is error-free management and enhanced regulatory vigilance (Holling 1986). From an ecological perspective we may soon have to question whether certain aspects of current economic policies are taking us in precisely the wrong direction.

5.5 A Consequences Decision Tree

Figure One is a simplified (and admittedly simplistic) look at the dilemma facing political decision-makers everywhere. Global change is either serious or it isn't, but they cannot know for sure. Assuming there will be public resistance to strong policy measures, the problem is one of choosing between an politically easy course that exposes society to potential hazard at an unknown level of risk, and a politically difficult course that may reduce the long-term hazard but imposes significant short-term costs on society.[9] To make the point, the figure boils these choices down to doing nothing (Levels 1) or taking decisive action (Level 4).

If the crisis is real and the decision-makers don't act, society is condemned. However, if they do act decisively and effectively, we will never know how great the hazard was. Ironically, this result might be indistinguishable from acting decisively in the absence of a real problem.

Which presents another difficulty: given the lag factor, it may be decades before the ecological consequences of either action or inaction are apparent, with or without a serious crisis. This is the worst of political situations from the perspective of accountability. Where there is public hostility to major adjustments, the only political pay-off comes from inaction. If the sky eventually does fall, today's recalcitrant political Chicken Littles won't be around to face the music.

Whatever the nature of present reality, Diagram 1 suggests that society can only benefit by acting decisively now. To delay is to invite disaster sooner or later. Even many (normally skeptical) scientists agree "that the unprecedented predicted rate of change warrants immediate action." Even with the remaining uncertainties, they recommend action now as insurance against future catastrophe (Mylot 1989b).

Clearly, it is better to act while we still have the time to plan and the capacity to implement an orderly transition to a more ecologically sustainable forms of development. The alternative may well involve the risk of social chaos in which case the ecosphere will impose a draconian solution of its own.

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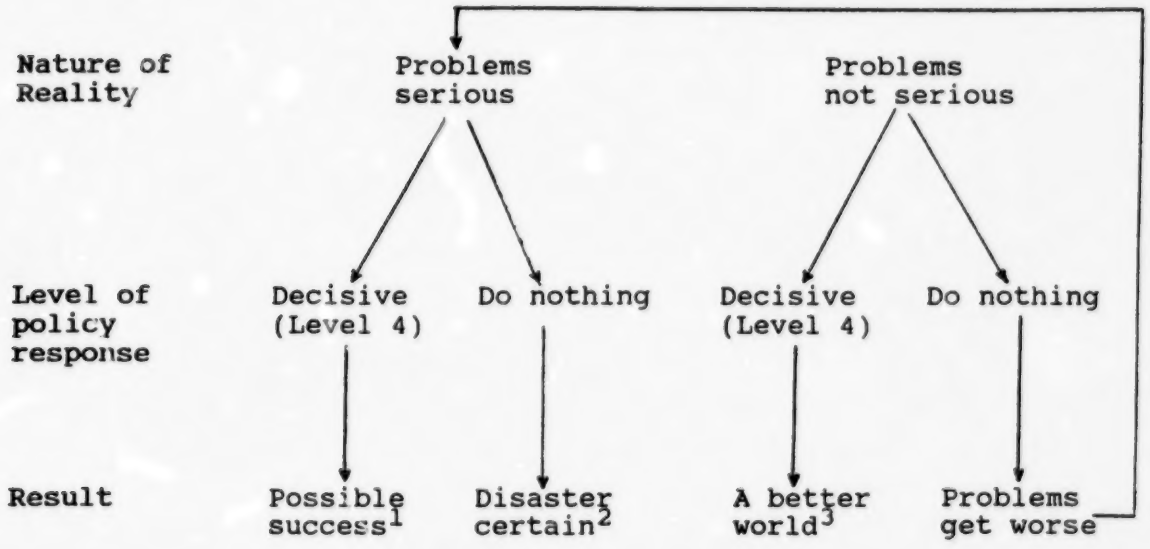
[9] If the public actually favours decisive action, the quality of the political choices shifts, but not the ecological outcome.

FIGURE 1

Consequences Decision Tree



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[1] A satisfactory solution is not guaranteed, even now.

[2] Ecological crisis puts survival of millions (billions?) at risk.

[3] A more energy and material efficient, ecologically benign, caring, and secure society.

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